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IMPACT OF A MILITARY REUSABLE LAUNCH VEHICLE ON DOMINANT MANEUVER AND FOCUSED LOGISTICS

GRADUATE RESEARCH PROJECT

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Abstract

This study analyzes the role of a next-generation reusable launch vehicle (RLV) as a potential defense mobility platform for the future. RLV prototypes offer rapid transportation anywhere on the globe within one hour, with a significant cost reduction from today's $10,000 per pound to $1,000 per pound of cargo through space. Unfortunately, extremely complex and time-consuming infrastructure and ground handling requirements hinder the usefulness of the RLV in a military environment. Joint Vision 2020 (JV2020) outlines operational concepts that mold warfighting capabilities to achieve full spectrum dominance in the future. Two of the operational concepts, dominant maneuver and focused logistics, shape mobility requirements and are used to evaluate the need for a military RLV. This project seeks to answer the question: "Could the next-generation RLV be a viable tool to support JV 2020's operational concepts of dominant maneuver and focused logistics?" The paper will begin by describing dominant maneuver and focused logistics, stating predictions concerning the future environment, and discussing doctrinal and cost management concerns. Next, the project will identify the RLV's history, capabilities, challenges, and a description of four major prototypes. This study will then link the operational concepts and the RLV capabilities to determine if a military RLV is a suitable transportation platform for the Department of Defense. Based on this analysis, current RLV prototypes do not meet the majority of criteria established by JV 2020's dominant maneuver and focused logistics. However, if a military RLV were designed and produced specifically for defense transportation, it could potentially overcome the reliability and flexibility obstacles and become a key enabler toward full spectrum dominance.

IMPACT OF A MILITARY REUSABLE LAUNCH VEHICLE ON DOMINANT MANEUVER AND FOCUSED LOGISTICS

I. Overview

The combination of speed, range, precision and lethality … make air and space power a formidable force for the nation – one capable of dominating enemy operations in all dimensions of warfare – land sea, air and in the future, space – across a spectrum of time and conflict.

-- General Ronald R. Fogleman, USAF, Retired

Introduction

The explosion of technology is having a profound impact on United States defense policies, potentially increasing the Armed Forces' ability to decisively wage war. Space technology is no exception, with its exponential growth producing opportunities that could revolutionize the United States defense system. Space is gaining recognition as a future battlefield on par with air, land, and sea (USSPACECOM Vision, 1997). Space superiority of the future could evolve into more than the communications, reconnaissance, and surveillance medium it is today, and may become the critical link to success in future warfare.

In Joint Vision 2020 (JV 2020), the Chairman of the Joint Chiefs of Staff outlined four operational concepts to enhance warfighting capabilities in the future: dominant maneuver, precision engagement, focused logistics, and full-dimensional protection. The exploitation of technology is a key factor in promoting these operational concepts, equipping the Armed Forces to conduct "faster, more lethal, and more precise" warfare in

2020 and beyond (JV 2020, 2000:1). The main thrust of mastering these operational concepts is to obtain "full spectrum dominance," gaining victory and control over the adversaries of the United States in all aspects of military operations (JV2020, 2000:3,6).

The acquisition and effective use of national and defense resources are critical to the successful implementation of JV 2020's operational concepts. One such resource, a next-generation reusable launch vehicle (RLV), is being designed and developed to rapidly transport cargo and passengers through suborbital and orbital space. This paper proposes that the development of RLVs has the potential to enhance global mobility in the coming decades, and in this role could further two of the four JV 2020 operational concepts, dominant maneuver and focused logistics.

RLV prototypes show a promising trend of successes that reveal the possibility of reaching their goal of travel anywhere on the globe within one hour. Other goals for RLV designs include cargo transport capability, reduced cost per pound for transport, and a substantially less complex maintenance and infrastructure profile than that required by their predecessor, the Space Shuttle. Supporters of RLVs have primarily focused on their applications as platforms in space, but the prospect of using the RLV as a mobility asset for the military has been largely unexplored.

For the RLV to meet success as a defense mobility asset, its operations must be as "aircraft-like" as possible, responding with similar reliability, flexibility, and supportability conditions that would allow the vehicle to integrate into the existing infrastructure. Designers would be challenged to demonstrate ease of maintenance, rapid turn around times, and standard infrastructure requirements in their prototypes. The intent of this paper is not to recommend a particular prototype, company, or design, but to discuss the types of RLV capabilities available to the military, what challenges arise with this vehicle, and whether a RLV could enhance JV 2020's goals of dominant maneuver and focused logistics.

Problem Statement

Department of Defense leaders, NASA, and the commercial industry have explored the use of RLVs to further the interests of the United States in the realm of space. Numerous prototypes are emerging to join the race for routine, affordable, and reliable space travel. The central focus of RLV designers and future users is to place and repair the intricate system of satellites in space. More recently, the goal has been expanded to include constructing and servicing the International Space Station.

This research pursues another potential use for the RLV. Could the RLV be a viable tool to support JV 2020's operational concepts of dominant maneuver and focused logistics in the future through terrestrial point-to-point travel? Several specific investigative questions are implied by this overall research question:

1. What operational requirements will emerge in the future?
    - What do JV 2020's operational concepts of dominant maneuver and focused logistics say about future mission needs?
    - How will the future global environment change, and how will the Armed Forces have to adapt to meet future mission needs?
2. What are the proposed characteristics of a next-generation RLV?
    - What is a next-generation RLV and how did it evolve?
    - What are its capabilities and challenges?

3. How do RLV capabilities compare with future mission needs?

   - How does the RLV fulfill the requirements of dominant maneuver and focused logistics?

   - Could the RLV contribute to other military or civil requirements?

Scope

The prospect of developing RLV technology opens the door to a multitude of issues, to include operational impact, cost, and technological feasibility. Since this paper cannot address all aspects of such a vast topic, the primary focus will be to discuss the operational impact of RLVs on global mobility. Although a brief discussion of the individual prototypes is included, a detailed analysis on cost challenges and the technologies used for RLV prototypes is beyond the scope of this paper.

Assumptions/Limitations

RLV technology is still in its infancy. Since an operational fleet has not been designed, conclusions and recommendations for this study will be based on extrapolations of current technologies, based on on-going research and stated RLV goals. Future mobility requirements are also not conclusively known. Due to the predictive nature of this topic, quantitative information is not available. The research method therefore was qualitative and based on opinions from mobility and space experts, as well as documents that focus on future requirements and capabilities, such as JV 2020, Air Force 2025, United States Space Command (USSPACECOM) Long Range Plan (LRP), and Air Force Doctrine Documents.

Organization of Research Results

The remainder of this paper is organized into five chapters. Chapter II discusses the mobility challenges and future mission needs presented in JV 2020. Chapter III introduces the RLV with a definition, history, description of technological challenges, and a review of four existing prototypes. Chapter IV ties the requirements together with the capabilities and supportability to show the operational impact of developing a fleet of RLVs. Finally, Chapter V concludes with recommendations for future research on this topic, and future research and development directions for the RLV program.

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II. Future Operational Requirements

*We are now transitioning from an **air** force into an **air and space** force on an evolutionary path to a **space and air** force.*

-- Global Engagement:
A Vision for the 21st Century Air Force

The turn of the century launched an exciting new era with technological advances that are transforming the way we live, work, and envision the future. The environment and circumstances surrounding the military of the future can only be predicted in broad terms, but the act of analyzing and forecasting defense needs is an exercise of great value. If defense leaders endeavor to design and procure a vehicle as complicated and financially demanding as a next-generation RLV, it will require years, conceivably decades, to make this dream a reality. Only by looking deep into the future, with periodic updates to sharpen our predictions, will we be prepared to face the challenges of tomorrow. After defining JV 2020, this chapter will take a broad predictive glimpse into the future military environment, followed by upcoming mission needs regarding doctrine and cost management.

Defining Joint Vision 2020

The vision of the Chairman of the Joint Chiefs of Staff of the United States Armed Forces is described in JV 2020. This template provides broad guidance for military operations of the future toward full spectrum dominance, defined as "the ability of US forces … to defeat any adversary and control any situation across the full range of military operations" (JV 2020, 2000: 6). JV 2020 also proposes that full spectrum dominance can best be achieved through four operational concepts: dominant maneuver, precision engagement, focused logistics, and full dimensional protection. This paper examines the RLV as a potential mobility vehicle through criteria outlined in dominant maneuver and focused logistics.

Dominant Maneuver

Air Force Doctrine Document 1 (AFDD 1), Air Force Basic Doctrine, describes "maneuver" as placing the enemy at a disadvantage, by having a command over distance and time, as well as by demonstrating flexibility and versatility (AFDD 1, 1997:17). JV 2020 defines "dominant maneuver" as:

> The ability of joint forces to gain positional advantage with decisive speed and overwhelming operational tempo in the achievement of assigned military tasks. Widely dispersed joint air, land, sea, amphibious, special operations and space forces, capable of scaling and massing force or forces and the effects of fires as required for either combat or noncombat operations, will secure advantage across the range of military operations through the application of information, deception, engagement, mobility and counter-mobility capabilities. (JV 2020, 2000: 20)

Dominant maneuver focuses on outmaneuvering the enemy with a more agile force that not only can position itself with speed, but also reposition itself to achieve surprise and mass. Dominant maneuver's requirement for flexibility and speed of movement leads to battlespace control and minimizes casualties of friendly forces by enabling the joint force commander to accurately position lethal power, leaving the enemy at a disadvantage. In peacetime, it can portray a sense of strength and unpredictability to potential adversaries and could prevent conflicts before they arise (JV 2020, 2000:20-21).

Focused Logistics

Focused logistics strives to reduce the logistics footprint required to sustain operations. It is defined as:

> The ability to provide the joint force the right personnel, equipment, and supplies in the right place, at the right time, and in the right quantity, across the full range of military operations. This will be made possible through a real-time, web-based information system providing total asset visibility as part of a common relevant operational picture, effectively linking the operator and logistician across Services and support agencies. Through transformational innovations to organizations and processes, focused logistics will provide the joint warfighter with support for all functions. (JV 2020, 2000:24)

Focused logistics requires both joint operations and integration with the civilian sector to disperse tailored logistics packages in “hours or days versus weeks” (JV 2010, 1996:24). Improving information and transportation technologies will yield a delivery capability that is able to place personnel and cargo where they are needed and when they are needed. JV 2020 emphasizes that “the increased speed, capacity, and efficiency of advanced transportation systems will further improve deployment, distribution, and sustainment” (JV 2020, 2000:25). Decisive global delivery will bring confidence and strength to future warfighters and will increase the United States’ ability to provide humanitarian relief to nations around the world (24-25).

AFDD 1 echoes JV 2020 as it speaks of the Air Force Core Competency of Rapid Global Mobility. It describes this capability as “the timely movement, positioning, and sustainment of military forces and capabilities through air and space, across the range of military operations” (AFDD 1, 1997:33). Logistics is often a crippling bottleneck in military operations. Mastering the complexities of logistics is a major aspect of successful warfare. AFDD 1 (1997:33) goes on to state that “global mobility has increased in importance to the point where it is required in virtually every military operation."

Future Environment Predicted

This chapter began with a quote that spoke of the relationship between air and space in the future. As we move from an "air" force to an "air and space" force, it is important to view mission needs from a perspective that includes space. USSPACECOM Vision 2020 describes the concept of space superiority as an emerging battlefield where dominance in space becomes as important to the fight as dominance in air, land, and sea. To secure this battlefield, the United States will need to develop the technology necessary to ensure superiority (USSPACECOM Vision, 1997). The concept of space superiority that exists today, denying the enemy the control and use of space-based information system assets, could only be a fraction of what space superiority means in ten or twenty years.

USSPACECOM Vision 2020 takes a deep look into the future of space warfare and identifies two major themes: "dominating the space medium and integrating space power" (USSPACECOM Vision, 1997). Dominating space as a future battlefield may require space access that is both routine and flexible, just as air superiority can only be secured by decisive and persistent access to air. In an environment where control of space is critical, "timely and responsive spacelift" will be key to space superiority in the future (USSPACECOM Vision, 1997).

Another aspect of "space as a battlefield," is that global engagement from space to earth will take on a significantly more robust meaning. USSPACECOM Vision 2020 describes global engagement as "the application of precision force from, to, and through space" by means of global partnerships that are "influencing space system designs" (USSPACECOM Vision, 1997). Although RLVs are far from routine in today's environment, a successful RLV program could make access through space as commonplace as access through air is today.

The commercial sector is quickly taking the lead in technological innovations for the future. By virtue of military budget cuts and the commercial sector's drive toward space access, the military is beginning to reduce its emphasis on owning technology and is becoming more comfortable with the concept of outsourcing capabilities. Air Force 2025 (AF 2025) asserts that spacelift of the future will be both reusable and jointly operated by the government and civilian industry (AF 2025, 1996). With even more urgency than today, the future may require the military to decide what it must develop and field itself, and what should be purchased or leased from the commercial sector.

Doctrinal Restructuring

Once the future is envisioned, defense leaders will have to take a serious look at how the Armed Forces plan to fight. It is logical to design doctrine to be forward-looking and precede technology rather than react to it. Unfortunately, many would argue that historically, the opposite is closer to reality. Space access at present is far from responsive, and Air Force doctrine in place reflects that non-responsiveness (Parker, 1999:7). AFDD 1 briefly addresses spacelift as one of seventeen air and space power functions. It defines spacelift as "delivering satellites, payloads, and materiel into or through space" and requires that spacelift be "functional and flexible, capable … timely and responsive" (AFDD 1, 1997:56). Although this criteria is respectable, USSPACECOM's LRP compiled in March 1998 recognized several doctrinal and command problems within space operations, and sought to solve them through "Full Force Integration" or integrating space with land, air, and sea operations (LRP, 1998: 73). The LRP states, "the process to request and task space resources are too complex, time consuming and cumbersome" (LRP, 1998:90).

To confront the inflexibility of space access, two doctrinal alternatives emerge. The first proposal, outlined by the USSPACECOM LRP, elevates space operations as a separate and equal component to land, sea, and air. This scenario could be interpreted to promote a Space Force that would break away from the Air Force just as the Air Force broke away from the Army to form a separate service (Parker, 1999:9). This new service would become responsible for organizing, training, and equipping space forces of the future. A newly formed space commission is preparing to bring this issue to Congress, with supporters like Senator Bob Smith (R-New Hampshire) who stated that "if the Air Force can not or will not embrace space power, we in Congress will have to drag them there, kicking and screaming if necessary, or perhaps establish an entirely new service" (Boyle, 2000).

The second alternative, supported by Secretary of the Air Force F. Whitten Peters and Air Force Chief of Staff General Michael E. Ryan is to develop an aerospace force equal to land and sea (Parker, 1999:9). Current doctrine, AFDD 2-2: Space Operations, states that air and space are intricately related and inseparable. An aerospace force sees space as a natural extension of air and one that can be managed under the same service

(AFDD 2-2, 1998:1). The goal of an aerospace force is to increasingly become more integrated, embracing space needs as equal to air.

Whether space branches off from the Air Force or remains integrated, the important issue is to begin focusing on space concerns and challenges (Parker, 1999:10). Even the best RLV fleet could be crippled if the process for the user to access the fleet is cumbersome. Restructuring doctrine and command relationships regarding space will play a major role in creating a military RLV capability that is routine and reliable for the future.

Cost Management

The enormous capability of the RLV has an equally enormous price tag that serves as one of the major barriers to its development. There are three ways RLV programs could receive funding: commercial/private funded, government funded, or commercial/private funded with government assistance. In November 1999 in Washington DC, a Space Transportation Roundtable examined RLV funding. The roundtable was attended by Senator Bob Graham (D-Florida), Senator Ted Stevens (R-Alaska), Boeing, Lockheed Martin, Kelly Space & Technology, Space Access, Kistler Aerospace, Orbital Sciences, Pioneer, Rotary Rocket, and Universal Space Lines, among others, who reached a consensus that the third option, commercial/private funding with government assistance, was the most beneficial way of achieving RLV goals (Scott, 1999:79).

The X-33, however, is the only RLV to date subsidized by the United States government for its design. NASA has funded the X-33 with $1 billion to date. Despite the subsidies, the X-33 has not won the contract for production of the VentureStar, and there are no guarantees that the transition from the X-33 to the VentureStar will be further subsidized, even if it is selected for purchase. The approximate cost to transform the X-33 to the full-scale VentureStar is $5 billion (Schonfeld, 1998). Although it is most cost-effective for the government to allow the commercial sector to design and produce RLV prototypes and fleets, the Department of Defense (DoD) may need to invest capital into the production of a military RLV if the commercial industry's motivation strays away from military-suitable designs.

Another important cost issue deals with reducing the amount of recurring costs per flight. The Space Shuttle, although deemed reusable, costs approximately $300 million per mission. Even though it has not been determined what cost per flight is appropriate for the next-generation RLV, it would need to be reduced significantly to be feasible as a defense logistics transporter. (Thompson, 2000).

The future of defense will be an environment characterized by fast-paced technological developments that could change the way the United States conducts warfare. JV 2020 establishes requirements through its operational concepts to meet tomorrow's warfighting needs. Dominant maneuver outlines the requirement for speed of movement and flexibility in deployment and redeployment to rapidly position and reposition forces. Focused logistics continues by highlighting the importance of a reliable and capable global delivery system that moves personnel and cargo accurately and on-time. The RLV is a potential enabler that could play a role in meeting future requirements, as long as the proper focus is given to doctrine, planning, and funding. Former USSPACECOM Commander in Chief (CINC) General Howell M. Estes III made this statement about RLVs prior to his retirement in 1998: “This is going to come along quicker than we think it is…we tend to think this stuff is way out there in the future, but it’s right around the corner” (Parker, 1999:23).

III. Reusable Launch Vehicle Capabilities

In addition to supporting terrestrial operations, many military functions previously performed by terrestrial forces may be accomplished by space forces.

-- Space Operations, AFDD 2-2

The desire for routine access to space via a next-generation RLV is stimulating innovative ideas that could make this dream a reality. This chapter will define what constitutes a "next-generation RLV," give a brief history of the RLV concept, and examine the requirements and challenges for the development of an RLV fleet. Specific requirements for an RLV designed for military operations will also be discussed. The chapter will conclude by summarizing four major RLV prototypes that are in development today, highlighting their unique capabilities and limitations.

Definition of a Next-Generation Reusable Launch Vehicle (RLV)

Our current spacelift capability in the United States consists of expendable launch vehicles (ELVs) and an operational first-generation RLV, the Space Shuttle. Although these vehicles are unmatched in their contribution to the United States space program, both ELVs and the Space Shuttle are expensive and inflexible. ELVs are similar in technology to modified, very expensive intercontinental ballistic missiles and are expended after one use. According to Schonfeld (1998) using an ELV is "like flying a Boeing 777 once—and then throwing it into the ocean." A single launch can cost anywhere from $10 million to $140 million (Schonfeld, 1998), or $6,000 to $8,000 per pound of freight (Thompson, 2000). An ELV can take months and sometimes even years to prepare for launch, which is far from suitable for a defense logistics system that requires vehicle turnaround in hours or days (Thompson, 2000). In order for space access to become routine, a new form of lift would have to emerge.

The Air Force has contracted with Boeing and Lockheed Martin to develop two families of expendable launch vehicles called Evolved Expendable Launch Vehicles (EELV). Boeing was awarded 19 EELV launches for its Delta IV family, while Lockheed-Martin's Atlas V program received a contract for nine launches. EELVs are designed to replace ELVs currently used by the Air Force, and are projected to reduce operational costs by 25% or more (Thompson, 2000). EELVs will achieve these savings through shared hardware, such as standardized cores for light, medium, and heavy lift vehicles (Olgeirson, 1998:3). According to Major General Robert Dickman, former Department of Defense Space Architect, "eventually, reusable rockets will push expendable ones out of the market for all but the biggest payloads" (Parker, 1999:14).

The Space Shuttle is the first generation of reusable launch vehicles and paved the way to acceptance and trust in a reusable capability for space transportation. However, the price tag of $10,000 per pound of cargo (GAO, 1999:5), coupled with a heavy launch and recovery logistical burden, brought into focus the need to develop a RLV that is economical and flexible. Although reusable in nature, the Space Shuttle still has 4,000 replaceable parts (The Space Shuttle, 2000) that add to the cost and maintenance burden. Like ELVs, the Space Shuttle's time-intensive launch and recovery sequences make it unsuitable for a defense mobility role (Thompson, 2000).

The goal of the next-generation RLV is to reduce the cost from today's $10,000 per pound to approximately $1,000 per pound. The RLV also provides flexibility and expanded operational capabilities over the ELV and the Space Shuttle, making them more attractive to Department of Defense leaders (Schonfeld, 1998). Some of the RLV goals asserted by designers include aircraft-like launch or recovery, rapid turn-around time in the order of hours, and heavy cargo carrying capabilities.

According to the RAND Project AIR FORCE Workshop on Transatmospheric Vehicles, one of the major differences that distinguish RLVs from aircraft is the means of propulsion. Current aircraft have air-breathing engines that cannot thrust the aircraft or be sustained above the atmosphere. RLVs have to overcome this dilemma with rocket propulsion and by transporting their own oxidizers (Bonds, 1997:1). They are capable of operating outside of the atmosphere, achieving unprecedented speeds from Mach 8 to Mach 25 (Stafford, 1997:6-7).

The term Transatmospheric Vehicle (TAV) is often used synonymously with RLV. In general, the term TAV incorporates vehicles with flexible propulsion systems, allowing them to operate within the atmosphere (using air breathing engines), and outside the atmosphere (using rocket powered engines). RLV is a more general term that identifies a group of vehicles that are designed to launch payloads into orbit. More recently, the title of Spaceplane has also been used in place of RLVs adapted for military use (Thompson, 2000). For the purpose of this paper, the term RLV will be used to refer to both military and commercial vehicles of all propulsion configurations.

Evolution of the RLV

Next-generation RLV technology has a history that spans from its infancy in the 1980s to mature prototypes for a variety of purposes to include satellite placement and repair, resupply of the international space station, and even space tourism (2000 Reusable, 2000:1). The early years did not meet with overwhelming success, but the promise of routine space transportation was a clear motivator that continued to further innovation. Although a fleet of operational next-generation RLVs has not yet been built, several experimental vehicles are under development to demonstrate a capability to transport people and equipment beyond the atmosphere and back.

In the 1980s, the DoD explored the concept of a National Aerospace Plane (NASP) with a "combined cycle air-breathing propulsion system" and a Single-Stage-To-Orbit (SSTO) capability that would enable the NASP to reach orbit and complete its mission without stage separation. Unfortunately, the NASP never materialized, with its propulsion technology classified as risky. The program was halted after $1.73 billion of research, with a projected production cost of $10 billion (Bonds, 1997:2).

In 1991, the Strategic Defense Initiative Office commissioned McDonnell Douglas to design and build the DC-X or the Delta Clipper-Experimental RLV. As a suborbital, SSTO traveler, the DC-X was designed to fly up to Mach 15 and at an altitude of 50 miles. It was built to a third of the actual scale and completed eight test flights, ending on July 7, 1995, after transferring to NASA the year prior. It was refurbished into the DC-XA and continued its test flights, exceeding operational parameters, including aircraft-like ground support, substantiated by two successful launches of this prototype in a single day (Stafford, 1997:6). In July 1996, the DC-XA was destroyed upon landing when one of its four landing gears did not deploy (Delta, 1998). Although the project ended after the crash, the Delta Clipper trailblazed a path for future RLV entrepreneurs.

The mid-1990s saw the birth of interest in the RLV concept among several commercial companies. At the same time, NASA initiated the development of a series of RLV technology demonstrators to include the X-33, X-34, and X-37. Some of the emerging prototypes incorporate a more aircraft-like design with horizontal landings and/or launches. The proposals use either rocket engines or a combination of rocket and air-breathing engines to achieve access to space. The X-33 is taking the next step in propulsion technology with its linear aerospike engines that are able to adjust to changing atmospheric conditions. The concepts also vary on whether the vehicles will incorporate SSTO design that allows the vehicle itself to deliver the cargo directly to space, or two-stage-to-orbit (TSTO) technology that enables the vehicle to separate in flight to achieve its mission (2000 Reusable, 2000:2).

RLV Technology and Infrastructure Requirements

SPACECAST 2020, one of the first initiatives to take a comprehensive look at preparing the United States for the future, discussed requirements for a military RLV. To be useful in a military environment, RLVs have to be "responsive (capable of launch on demand), highly reliable, able to abort a launch without destroying the vehicle (soft abort), resilient, flexible, logistically supportable, and easily operated ... [and] affordable" (SPACECAST, 1994). The RAND Corporation echoed these significant requirements in 1997 in its Project AIR FORCE Workshop on Transatmospheric Vehicles. RAND stated that military RLVs must have "rapid launch-on-alert capability, unpredictable launch schedule, fast turnaround time, and rapid reconfigurability to handle a variety of payloads" (Bonds, 1997:17). These requirements are general guidelines for RLV design to meet military needs.

For a more specific list of criteria for a defense RLV, Phillips Laboratories produced a Technical Requirements Document (TRD) for a military RLV (called the "Military Spaceplane") in 1995. The TRD was created for an Integrated Concept Team formed by Air Force Space Command. These requirements included a payload carrying capacity of 15,000 pounds (Thompson, 2000), a vehicle turn time of seven days, and an emergency launch capability within hours. According to Phillips Laboratories, the vehicle must have an operational availability rate of 90% or better, regardless of weather (Bonds, 1997: 14).

RAND Corporation continues by evaluating responsiveness and flexibility requirements. For the RLV to be suitable for military operations, it may require an alert status capability. Although RLV and aircraft requirements for alert will have significant differences, a military RLV may need the ability to launch on demand. RAND describes flexibility requirements as the ability to place a payload in numerous orbits and launch from a multitude of air bases for increased survivability. Further, a military RLV would call for a large cross-range for reentry into the atmosphere to ensure there is an adequate abort capability, especially if a large basing variety is not available (Bonds, 1997: 14-16).

The infrastructure requirements for RLV technology will depend on the technology itself. If RLVs are able to achieve aircraft-like requirements for runway launch and recovery, maintenance expertise, fuel, and cargo loading and unloading, the infrastructure requirements will be minimal, and RLV fleets can be envisioned alongside aircraft in operational wings. However, if military RLVs resemble the Space Shuttle more than an aircraft, infrastructure challenges will severely limit the vehicles' flexibility, responsiveness, and supportability.

It is important to note that no one vehicle can completely satisfy all the requirements for space access, just as no one aircraft can complete all missions in the air. Scores of RLV designs are in work by the government and the commercial sector, each with its own unique capabilities and challenges. It is highly probable that the military would need more than one RLV type to achieve its entire list of requirements. The future scenario could also mirror airlift today in that military RLVs may be augmented by RLVs in the commercial sector, similar to the current defense mobility system augmenting organic airlift with commercial carriers like Federal Express (Thompson, 2000).

Technological Challenges for RLV Designers

RLV producers have significant technological obstacles to overcome when designing and building RLVs. Penetrating atmospheric bounds is a brutal endeavor for a vehicle to endure repeatedly, especially in the reentry phase. Vehicle weight reduction, propulsion, thermal shielding, fuel mixture, speed, and passenger/cargo capability are just a few of the concerns to overcome. Engineers have to use existing technology found in the Space Shuttle and take it to the next level of performance while maintaining a strong emphasis on safety. One error in technology could lead to catastrophic results for the crews, passengers, and cargo.

RLV designers have to overcome the challenge of making the vehicle both lightweight and durable. Composite technology allows manufacturers to create RLVs with sufficient strength-to-weight ratios far beyond standard metals. As this technology advances, RLV weights could reduce as much as 35 percent of current prototypes (Bonds, 1997:xviii).

Propulsion is a second technological challenge that RLV designers face. Engine designs for such a far-reaching mission as space have to be both efficient and powerful. One of the most reliable and effective propellant combinations for RLV engines is cryogenic liquid hydrogen (LH2) and liquid oxygen (LOX). However, this combination is highly explosive and not very suitable for routine military operations (Bonds, 1997:xix). A more stable, but less effective option is a high-density propellant, such as kerosene. High-density propellants are used on ELVs today, making this option simpler from an infrastructure standpoint (Thompson, 2000). With more research, the high-density propellant option may prove to be a more useful fuel source for the future (Bonds, 1997:xix).

Thermal Protection Systems (TPS) are required to withstand the high thermal load on RLVs while reentering the atmosphere. Although locations that receive peak temperatures would still need carbon-carbon reinforcement, RLVs are exploring the use of metallic panels instead of the ceramic panels used on the Space Shuttle, that need 17,000 refurbishment man-hours following each flight (Bonds, 1997:xx). According to Lieutenant Colonel David Thompson, Chief of the Spacelift Vehicle Requirements Branch at Air Force Space Command, “The key for TPS is that it needs to be cheap, rugged and a part of the vehicle structure. Today we can’t even fly the expensive TPS we use through the rain without going to great lengths to dry it out before going into space” (Thompson, 2000). The metallic tiles are lighter and eliminate the need for an adhesive system and load-bearing structures. RLV designers are optimizing design techniques to reduce the need for thermal protection (Bonds, 1997:xx).

Overview of the Major Prototypes and Their Design Goals

In spite of the seemingly insurmountable challenges that RLV designers face, the race to build the first operational RLV is alive and thriving. The number of RLV prototypes continues to increase at a remarkable rate. Each prototype is unique and ranges vastly in capability, limitations, intent, and projected completion dates. A key component of examining RLVs in light of dominant maneuver and focused logistics is to study the various prototypes that are currently being envisioned, planned, and produced. Although some are more conducive to military mobility operations than others, none currently are being designed specifically for point-to-point terrestrial transportation.

This section will describe four major prototypes, the Pathfinder Spaceplane by Pioneer Rocketplane; the Roton by Rotary Rocket Company; the Astroliner by Kelly Space & Technology; and the VentureStar, a joint NASA-Lockheed Martin effort. For every prototype described here, there are a host of other designs that bring dynamic innovations of their own to the table. The intent of this section is not to advocate one prototype over another, but to provide a brief set of examples describing upcoming capabilities in the RLV development field.

Pathfinder Spaceplane by Pioneer Rocketplane

The Pathfinder Spaceplane is a two-stage-to-orbit (TSTO) vehicle that incorporates two Pratt and Whitney F100 conventional air-breathing engines and one

RD-120 LOX/RP rocket engines into its design. It requires a two-person crew and is able to carry up to 4,000 pounds of cargo. The spaceplane is designed to take off and land from a normal runway, making it versatile from an infrastructure standpoint.

Figure 1:
Pathfinder Spaceplane
(Pioneer, 2000)

The Pathfinder requires an in-flight transfer of LOX from a modified tanker aircraft after take off. After the tanking, Pathfinder's kerosene-fueled RD-120 rocket engine ignites for travel beyond the atmosphere. At 70 nautical miles, the upper stage ejects and delivers the payload. Upon reentering the atmosphere, the turbofan engines re-ignite for landing on a conventional runway. It is able to carry a payload of 4,000 pounds to a low earth orbit (LEO). The Pathfinder Spaceplane is estimated to be ready for operation three years after full financing (Pioneer Rocketplane, 1999).

Roton by Rotary Rocket Company

Figure 2: Roton
(Rotary, 2000)

The Roton is a Single-Stage-to-Orbit (SSTO) RLV that is crewed by a pilot and a cargo specialist. It takes off and lands vertically, and is powered by a liquid-fueled Fastrac engine that burns LOX and kerosene. This unusual engine is mounted on the Roton's base and uses centrifugal force to fuel 96 combustion chambers (Parker, 1999:18).

The Roton uses an autorotating, nose-mounted rotor for a softer and more controlled reentry and descent. The rotor is deployed in space and allows pinpoint landings with the assistance of tip-mounted thrusters. It is able to carry a cargo load of up to 7,000 pounds to a LEO and is projected to cost $1,000 per pound (Roton, 2000). It has the added appeal of being able to return to earth with a full load of cargo.

Rotary Rocket is expected to build an initial fleet of three to five vehicles that can each accomplish a minimum of 100 flights (Mehuron, 1998:28). The Roton is meeting with initial success, completing a smooth test flight in October 1999. This unique RLV is expected to be operational by the year 2002 (Roton, 2000).

Astroliner by Kelly Space and Technology

The Astroliner is piloted and TSTO. It will be towed to a height of 20,000 feet by a Boeing 747 before being released on its own engine power. The Astroliner's towing capability has been successfully demonstrated over six times using both a C-141 and a QF-106 (Mehuron, 1998:28).

Figure 3: Astroliner
(Kelly, 2000)

Its rocket engines propel the spacecraft to 400,000 feet before releasing its second stage. This expendable second stage is able to deliver cargo to a LEO while the reusable vehicle returns to earth (Kelly, 2000), landing as an aircraft on a normal runway of at least 10,000 ft long (Mehuron, 1998:28). It incorporates off-the shelf technology in propulsion, guidance, heat shielding, and avionics for a more reliable and less expensive design. The Astroliner carries up to 11,000 pounds of cargo to a LEO at a cost of approximately $2,000 per pound. This RLV is projected to be operational in 2002 (Kelly, 2000).

VentureStar by Lockheed Martin

Figure 4: VentureStar
(VentureStar Gallery, 2000)

The X-33 is a half-scale prototype of the Lockheed Martin's VentureStar. It is a technology demonstrator that will be able to take off vertically, and land horizontally like an aircraft on a standard runway. Unlike the VentureStar, the X-33 will be sub-orbital, unpiloted, and will not carry a payload (VentureStar: Operations, 2000). Two XRS-2200 linear aero-spike engines with one liquid oxygen and two liquid hydrogen fuel cells propel this prototype. Its fuel system is lightweight, and it has a metallic thermal protection system (Walker, 1999:5). The X-33's designed turn-around time is seven days, with a two-day surge capability X-33, 2000).

The VentureStar is programmed to have seven linear aero-spike engines and is designed to deliver 44,550 pounds of cargo to LEO and 24,750 pounds to the International Space Station. Other goals include a further reduction of the X-33's $1,000 per pound to $135 per pound to LEO. The VentureStar is proposed to demonstrate seven-hour turn times between flights with an emergency capability of three and a half hours (Walker, 1999:4-5).

Despite the X-33's progress it has had its share of failures. Flight tests were scheduled to begin in the summer of 2000, but were postponed indefinitely due to defects in its fuel tanks. Fractures and delamination along the honeycomb of the X-33's right hydrogen tank's lobe #1 are threatening the existence of the program (Dornheim, 2000). Cost overruns due to technical problems with the heat shield, fuel tanks, and engines, as well as a projected speed reduction from Mach 15 to Mach 13.8 due to greater than anticipated vehicle weight estimate, are other problems emerging from the program. If the ambitious X-33 program meets success in the end, Lockheed-Martin plans to build the VentureStar at a cost of $7.2 billion for two operational vehicles. Current schedule predicts cargo flights to begin in 2005 and passenger flights to the International Space Station in 2007 (Li, 1999:1, 3).

Summary of RLV Prototypes

These prototypes represent both the potential success and the difficulties in creating an RLV that is flexible enough to excel in military operations. The Pathfinder Spaceplane has the tremendous advantage of being able to take off without assistance and use conventional runways for both take off and landing. The requirement for immediate augmentation for LOX transfer by a specialized tanker aircraft reduces the versatility and responsiveness of this vehicle. This somewhat parallels the requirement to refuel long-range, heavily loaded mobility aircraft after take off in today's environment. However, LOX transfer is a more volatile procedure.

The Roton's pinpoint landing system could greatly benefit the military mobility missions. It also has the ability to land fully loaded, making it more flexible as a mobility transporter. Unfortunately, the vehicle's lack of maneuverability and aircraft-like design limit its usefulness in a combat environment.

The Astroliner's primary use of existing technologies will make supply of parts and skilled maintenance technicians readily available, unlike most of its competitors. The need for a Boeing 747 tow, however, detracts from its suitability for military mobility. Reliability will depend not only on the Astroliner, but also on the Boeing 747.

The VentureStar is designed to reach orbit unassisted by a tanker or tow aircraft due to its linear aerospike engines. It carries a significantly larger payload than the other prototypes studied in this paper. NASA has selected the X-33 to receive subsidies, but does not guarantee that the VentureStar will be selected for use by the United States government. Although well suited to work with satellites and to resupply the International Space Station, the VentureStar's vertical launch system makes it less than ideal for military operations. The VentureStar has the disadvantage of a late completion date, giving other prototypes time to establish themselves in the market before the VentureStar becomes operational.

The Pathfinder Spaceplane and the Astroliner use a TSTO design that focuses on payload delivery in space rather than point-to-point terrestrial transportation through space. However, a point-to-point delivery capability is not inconceivable if this TSTO design were altered to deliver cargo to a point short of orbit. The ballistic trajectory could then transport the cargo on a path to some point on the earth. By controlling the "burnout conditions" of height and velocity, the cargo's reentry point and destination may be determined. If a procedure is designed to protect and control the cargo during descent and reentry, it would be possible for a TSTO vehicle to deliver cargo to earth in this unconventional way (Thompson, 2000).

With JV 2020 outlining the criteria for future success in military operations, the RLV presents itself as a prime candidate to fulfill these defense mobility requirements for the future. To determine whether the RLV is capable of effectively performing as a defense transporter, it must be evaluated specifically based on the future mission need. Chapter II took the first step by identifying the predicted future operational needs. This chapter took the second step by identifying key capabilities and challenges for RLV. Chapter IV follows with a comparison between the predicted future mission needs and the estimated RLV capabilities.

IV. Operational Impact

The medium of space is recognized as the fourth medium of warfare. Joint operations require the Control of Space. [Control of Space requires] timely and responsive spacelift.

--USSPACECOM Vision 2020

The goal of any predictive analysis is to begin the journey from vision to solid operational capability. With JV 2020 as the vision and the RLV as a potential transportation capability, the operational concepts of dominant maneuver and focused logistics can act as a vital link in determining the necessity of the RLV. If RLVs are found to be of military value, then the natural next step for defense leaders would be to decide what characteristics this vehicle must have and move toward achieving that end.

The RLV and Dominant Maneuver

JV 2020's definition of dominant maneuver, found in Chapter II of this paper, outlines two concrete goals: positional advantage, and flexible and widely dispersed forces (JV 2020, 2000:20). Positional advantage is further described as being achieved through decisive speed and a high operational tempo. Viewed through this definition, the RLV's strengths and weaknesses can be seen more clearly. The RLV's overwhelming advantage is decisive speed. A joint forces commander who is able to position personnel, equipment, and supplies to any location globally within an hour possesses decisive speed to a degree that is hard to imagine today. That commander would be able to execute positional changes before an adversary with less technical capability had time to react. Decisive speed would bring with it the advantage of surprise, and the RLV has the potential to play a strong role in securing military victory in future battle through its unprecedented speed.

Conversely, dominant maneuver's emphasis on performing at a high operational tempo is an area where the RLV falls painfully short. Although many of the major prototypes aim to be aircraft-like, the reality is that with their attempts to penetrate the earth's atmosphere, operational obstacles arise that make the vehicle unable to launch, recover, and launch again with any degree of speed or simplicity. In order to support this aspect of JV 2020, the RLV would have to be designed to require little or no specialization in ground handling, be able to return to flight in less than a day, and become routine, less expensive, more rapid, and more versatile (SPACECAST, 1994). The prototypes today have not achieved this level of sophistication.

The second goal of dominant maneuver is to have forces that are flexible and widely dispersed. This flexibility comes from the commander's ability to scale and mass forces (JV 2020, 2000:20). In other words, there is great military value in not only positioning forces, but also in repositioning them at will to achieve a desired end. Using the RLV, whose speed is derived from traveling beyond the atmosphere, would not be a logical choice for short-distance movements. The limited cargo carrying capability of most prototypes also hinders the scaling and massing requirement for large personnel or cargo loads. On the other hand, repositioning smaller contingents across the globe may be a logical use for the RLV, as well as inserting a highly trained, decisive force at a key moment. These actions could turn the tide of a conflict or even prevent its escalation. The limitations for RLV load capability are not rigid, however. Current prototypes are built for space-related missions, not for global mobility. A military RLV would have to be designed with dominant maneuver in mind in order to be truly useful in dispersing forces.

The RLV and Focused Logistics

JV 2020 breaks down focused logistics into four categories: the right personnel and cargo, the right place, the right time, and the right quantity. These categories relate to supporting joint forces in action (JV 2020, 2000:24). The right personnel and cargo category is a versatility issue. Current RLV prototypes are far from satisfying the military versatility requirements, but it is conceivable that the RLV could become a responsive force mover if it is successfully designed and manufactured to meet this mission. Such a vehicle would have to break away from the commercial pack that is driving toward cargo-only designs. A versatile RLV that could transport personnel, equipment, and supplies would need the ability to quickly reconfigure for general passengers, dignitaries, patients, cargo, or a combination load.

The right-place category deals with the ability to transport critical forces wherever they are needed, to include austere or hostile locations. From delivering cargo to combat zones, to bringing life-saving supplies for a humanitarian cause, to moving critically wounded personnel on an air/space-evacuation mission, rugged flexibility is the key. None of the RLV prototypes today could fully meet this mission. They could, however, augment tactical and aeromedical air assets in a strategic role, speeding the delivery process while avoiding austere or hostile situations, in other words, a low-density, high demand asset used in particular and specialized cases.

The right-time category highlights the RLV's advantage of speed in flight, and disadvantage of complexity in launch, recovery, and ground support. The fantastic speed generated by the RLV is limited by its lack of responsiveness, and therefore restricts its usefulness for defense mobility missions. As technology matures over time, however, it is quite conceivable that the RLV will someday match the responsiveness of aircraft. At that point, the RLV could excel as a military force projection platform.

Finally, moving forces in the right quantity mirrors the problems and potential achievements mentioned with widely dispersing forces. Cargo and passenger load capabilities in most prototypes are not such that they can move large forces. To overcome this shortfall, defense leaders will have to specify the need for increased carrying capacity, or contract to build more than one type of RLV. It may come about that a small RLV that is more maneuverable but restricted in cargo load, may be designed in addition to a larger, less maneuverable RLV that is able to carry over- and out-sized cargo.

Table 1 summarizes how well the RLV fits JV 2020's criteria for dominant maneuver and focused logistics. It illustrates that the RLV has more challenges than immediate benefits to the military mission, especially in the area of focused logistics. With that said, the improvement areas listed in Table 1 could greatly enhance the capability of the RLV. The question is not so much whether the RLV is right for the military in its current state, but whether it could be designed to meet future military needs. If these improvements are technologically achieved and incorporated into a single or series of vehicles designed specifically for defense mobility, the RLV may be the right answer for defense transportation of tomorrow.

Table 1: Comparison of Future Mission Needs and RLV Capabilities

Future Mission Need	Meets Need	Doesn't Meet Need	Improvements for Areas that Don't Meet Future Mission Needs
Dominant Maneuver:			
Positional Advantage *Decisive Speed*	X		
Positional Advantage *High Operational Tempo*		X	Design RLVs to be more aircraft-like in terms of reliability & maintainability
Flexible, Widely Dispersed Forces *Large Forces or Short Distance*		X	Increase cargo and passenger carrying capacity
Flexible, Widely Dispersed Forces *Small Forces or Long Distance*	X		
Focused Logistics:			
Right Personnel and Cargo		X	Design RLVs to be easily reconfigured
Right Place		X	Create a RLV that has the flexibility to handle a multitude of environments
Right Time *Speed of Launch and Recovery*		X	Simplify maintenance and infrastructure requirements
Right Time *Speed of Delivery*	X		
Right Quantity		X	Either increase payload & passenger area or create more than one RLV type

Other Potential Applications for the RLV

Outside of mobility, the RLV has a host of potential uses that could help justify its design and procurement. A vehicle that could perform both mobility and space missions would be the ideal spacelift platform. In addition to global mobility, a military RLV could be constructed to access space to deliver and maintain communications, surveillance, and reconnaissance satellites. It could also have the capability to deliver personnel or payloads in orbit in support of the international space station or space exploration.

From the combat perspective, the RLV has tremendous potential to add to the United States' warfighting strength, if it is programmed and designed effectively. SPACECAST 2020 asserts that the RLV would enable United States forces to "rapidly respond worldwide to future threats with overwhelming offensive firepower. It provides the national command authorities (NCA) and the CINC the ability to accomplish strategic level effects in about an hour without using weapons of mass destruction" (SPACECAST, 1994). For example, the RLV could act as a bomber, attacking multiple targets with speeds that overwhelmed the enemy and limited the vehicle's vulnerability to ground or air based threats.

Finally, the RLV opens exciting opportunities for the commercial industry and economy through routine access to space. Business and leisure travel standards could take a substantial leap if the RLV made routine space access a reality. Employment opportunities in the design, construction, maintenance, and operation of RLVs could boost the economy if this industry grows, as did its air counterpart. If this capability is harnessed quickly enough, the United States would become the world leader in this market and could remain so indefinitely.

The military certainly benefits when the high cost of developing an RLV is partially absorbed by innovation in the commercial industry. Therefore, motivating the private sector to further RLV technology is a worthwhile endeavor for the DoD. The commercial market may respond to a CRAF-like arrangement where they receive peacetime incentives for wartime commitment, motivating more companies to design and build flexible RLVs that are able to adapt to specialized military operations (Surina, 2000).

RLV technology has the potential to impact the military defense system and the lifestyles enjoyed by society. From the mobility perspective, dominant maneuver and focused logistics highlight future mission requirements that current RLV prototypes do not adequately meet. By taking the initiative to design a mobility-specific RLV and motivate the commercial industry to produce it, the DoD’s opportunity to benefit from this technology will be greatly enhanced.

V. Conclusions/Recommendations

Persuasive in peace, decisive in war, and preeminent in any form of conflict.

-- Joint Vision 2020

Summary

Thinking back thirty years to the level of technology of that day gives us a glimpse of how innovation can change the environment in which we live. "Black-and-white television with only 3 channels, operator assistance for long-distance telephone calls, mechanical cash registers … slide rules, analog instruments, and punch cards for batch processing" were the norm for that time (AF 2025, 1996). Compare that picture with today's world of "cable TVs with 150 channels … direct broadcast satellites … automatic teller machines … and the World Wide Web" to see the difference a few decades can make (AF 2025, 1996).

JV 2020 directs our thoughts two decades in the future and challenges today's defense standards by envisioning tomorrow's possibilities. JV 2020's four operational concepts can serve to focus innovation toward specific military goals that could solidify the future success of the United States Armed Forces. Two of the four operational concepts, dominant maneuver and focused logistics, provide definitive guidance for mobility requirements of the future. This paper addressed the use of a next-generation RLV as a defense transportation asset, analyzing this upcoming capability with the criteria set up in dominant maneuver and focused logistics.

The technological challenges that arise when considering routine access to space are certainly substantial, with issues like weight reduction, propulsion, thermal protection, and the resultant cost per pound, but the drive toward overcoming these obstacles in the commercial aerospace industry is breaking down these barriers at a remarkable rate. Although a military RLV is not in development, existing prototypes of various forms are demonstrating that routine access to space is well on its way to becoming a reality.

Another great challenge for the military will be to incorporate the technology in a smooth, operationally sound, flexible, and logical manner. Doctrine is the key to enabling space operations to move from its present state to a more expanded future role. With RLV technology developing so rapidly, the Air Force should begin to consider ways to make space access less cumbersome. The slow pace of doctrinal change seen in the past would only serve to hinder the tremendous growth potential in the arena of space.

An analysis of dominant maneuver and focused logistics show that RLV designs, as they stand today, do not meet tomorrow's defense mobility needs. The RLV does, however, possess the potential to be harnessed into an indispensable tool for the future. The challenge for defense leaders is to decide whether this capability is worth pursuing. If building a military RLV is deemed best for the defense of the United States, then the role this vehicle will play must be clearly outlined (combat or mobility, strategic or tactical, light or heavy lift, passengers and/or cargo). By narrowing down the precise function of a defense RLV, the foundation will be established to begin planning, programming, and designing such a vehicle. Once this is accomplished, the DoD can leverage the support of the commercial industry, or augment them to overcome the enormous developmental costs.

Recommendations for Additional Academic Research

The RLV is an exciting technology with a host of unanswered questions. Researching the possibility of using the RLV for defense mobility has revealed other areas that can benefit from academic study. A logical follow-on research project would include a detailed study on the technological challenges discussed in this paper: a strong and light-weight composite structure, a versatile and reliable propulsion system, a safe and efficient fuel mixture, and a durable thermal protection system that is easily maintained.

The logistical support burdens of the major prototypes would also make an excellent research project, as logistics is one of the primary limiting factors surrounding military acceptance of the RLV. Topics such as turn around times, required maintenance procedures, supplies/fuel access and distribution, infrastructure demands, integration into tomorrow's war plans, interface with commercial industry, and environmental concerns all need exploration prior to a decision to design a military RLV.

A dynamic research study could be done on other uses for the RLV. Air Force 2025 speaks of the "supporting pillar for space superiority," describing a new vehicle called "multipurpose transatmospheric vehicle (MTV) for "intelligence, surveillance, reconnaissance, global mobility, and strike" (AF 2025, 1996). All of these areas would benefit from more academic study.

A comprehensive cost analysis for a military RLV fleet is an area prime for research. With decreasing defense funds, cost concerns will be one of the decisive factors in determining whether the United States should pursue the RLV for the military. Cost figures are needed for research and development, design, production, and maintenance of a military RLV fleet. Another significant research area is a cost analysis determining the point at which the RLV becomes competitive from a recurring cost standpoint (Thompson, 2000).

Finally, doctrinal modifications necessary for the efficient management of routine space access through an RLV fleet is an important area for academic research. The issue of separating or integrating space with air should be continually evaluated as the role of space in the Armed Forces grows beyond its present state. Studies could include a comparison of the efficiencies associated with separating space from air operations or keeping them integrated as an aerospace force.

Recommendations for Future Research and Development

If the DoD opts to consider a military RLV fleet, and the funding exists, then the next step is to conduct research and development to establish if such a vehicle can be built. It is not certain whether current technology could produce an aircraft-like vehicle that can also conquer the challenges of space travel. Scientific research in this area would clear up the uncertainty and allow military leaders to make an educated decision on the RLV issue.

Research and development focused on a military RLV can investigate technology that would allow the RLV to operate in austere environments, have stealth characteristics, use safe fuel sources, take off and land horizontally and unassisted, and be compatible with civil aviation capabilities to name only a few possibilities. Although the technology is promising, without breakthroughs in these areas, the RLV would be primarily limited to applications in space.

The question of whether RLV technology is necessary for the defense transportation system is certainly not clear cut, but the possibility is strong that the future will see a vehicle that could operate effectively both in air and space with minimal support requirements. Until that day, defense leaders have several options: they could reject or postpone RLV development, contract existing RLV designs for limited mobility use, or design a military RLV from ground up to meet as many defense transportation needs as current technology allows. The decision must be made based on facts from academic research in all areas concerning the RLV, and research and development efforts covering key technologies. In many ways we can affect our future by the decisions we make today rather than just react to it. This is the goal of JV 2020. Analyzing potential technologies such as the next-generation RLV through the lens of operational concepts like dominant maneuver and focused logistics puts the military well on its way toward achieving full spectrum dominance.

Appendix: Glossary of Acronyms

AF 2025	Air Force 2025
AFDD	Air Force Doctrine Document
CINC	Commander in Chief
DC-X	Delta Clipper-Experimental
DoD	Department of Defense
ELV	Expendable Launch Vehicle
EELV	Evolved Expendable Launch Vehicle
GAO	General Accounting Office
JV 2010	Joint Vision 2010
JV 2020	Joint Vision 2020
LEO	Low Earth Orbit
LRP	Long Range Plan
LH2	Liquid Hydrogen
LOX	Liquid Oxygen
MTV	Multi-purpose Transatmospheric Vehicle
NCA	National Command Authorities
RLV	Reusable Launch Vehicle
SSTO	Single-Stage-To-Orbit
TPS	Thermal Protection System
TRD	Technical Requirements Document
TSTO	Two-Stage-To-Orbit

USAF	United States Air Force
USSPACECOM	United States Space Command

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Vita

Major Nanette M. Williams was commissioned through the Reserve Officer Training Corps at Cornell University in May 1988. After graduating from the Aircraft Maintenance Officers Course at Chanute Air Force Base, Illinois in 1989, she transferred to Travis Air Force Base, California and served as the Officer in Charge of the Sierra-16 Branch for C-5 maintenance, Aerospace Ground Equipment Branch, Propulsion Branch, Quality Assurance, and Flight Commander for the Red Sortie Generation Flight for C-141 maintenance. In 1993, Major Williams attended Squadron Officer School at Maxwell Air Force Base, Alabama with a subsequent tour to Bitburg Air Base, Germany where she served as Flight Commander for the Propulsion Flight and Squadron Section Commander for the 36th Maintenance Squadron. In 1994, she was transferred to McChord Air Force Base where she was the Flight Commander for the Blue Sortie Generation Flight and the Maintenance Supervisor for the 62d Maintenance Squadron. Major Williams was then chosen for a two-year cross flow to the transportation career field at the 62d Aerial Port Squadron, where she served as the Flight Commander for the Passenger Service Flight and Air Freight Flight. Major Williams moved to Grand Forks Air Force Base, North Dakota in 1998 to work as the Maintenance Supervisor for the 319th Maintenance Squadron. In 1999, she was selected for the Advanced Study of Air Mobility Course at the Air Mobility Warfare Center on Fort Dix, New Jersey.